

MODERN ROUNDABOUTS, GLOBAL WARMING, AND EMISSIONS REDUCTIONS: STATUS OF RESEARCH, AND OPPORTUNITIES FOR NORTH AMERICA

Executive Summary

The escalating rate at which modern roundabouts are being built at North American intersections holds a significant potential for conserving energy, reducing air pollutants and addressing global warming. Modeling and empirical studies of busy highway intersections document a substantial short term benefit from installing modern roundabouts. Motor fuel consumption and associated air pollutants are reduced, and the primary global warming gas (GHG), CO₂, is significantly cut. The modern roundabout arrived in North America in 1990 and has rapidly increased in numbers. The US and Canada urgently need a variety of strategies to return to GHG generation to levels below those of 1990 by 2012. The roundabout is one such strategy. Two decades of intersection control modeling and software development and research, establish that substantial fuel savings at busy intersections can be gained by employing roundabouts rather than traffic signals. Reduced fuel consumption—and by extension pollution emissions and GHGs—are demonstrated through analysis of empirical data and modeling reported from existing US roundabouts and those under development.

The magnitude of impact from roundabouts on Vermont statewide motor fuel use is suggested by a hypothetical installation of roundabouts in place of signals at 100 busy intersections.

According to models, this change would decrease total annual motor fuel use by approximately 8% of 1997 statewide consumption. The effect of a modest number of roundabouts on various climate action plans is probed by estimating an arbitrary number of intersections transformed to roundabouts. It is suggested that 25 roundabouts replacing existing traffic signals in the City of Burlington, Vermont would equate to over 20% of that City's goal of bringing GHG emissions to 10% below the base line 1990 level. The value and effects of increasing numbers of roundabouts in North America need to be explicitly incorporated as planners develop policies and strategies for energy conservation, global warming and air pollution.

The longer term potential for roundabouts to reduce resource use—including pollution and GHGs--by enabling higher density land uses and fostering increased transit and non-motorized modes has been documented elsewhere. Roundabouts are generally acknowledged to be superior in all aspects of performance to alternative intersection controls. Roundabouts usually recover their capital costs in a few years through savings to all users in reduced crashes and crash severity, time delay, maintenance, and fuel savings.

Introduction

This paper reviews a portion of the literature on roundabouts and pollution emissions; describes the Australian intersection model and the lack of a comparable US model; reviews applications of the Australian model to US intersections; and concludes by evaluating the impact of installing roundabouts in the City of Burlington as a strategy to implement its plan for global warming gas reduction to below 1990 levels. Results of evaluation of stop delay at the first two-lane roundabout installed in the northeast at Brattleboro, Vermont, in 1999 is also presented.

Modern Roundabout History

Traffic signals, roundabouts, and stop control all fall under the transportation category of “intersection control devices.” The traffic circle, the modern roundabout predecessor, as an intersection control device dates from 1905 when the first one, Columbus Circle, began to

operate in New York City. Traffic circles are large, high speed and historically, entering traffic had priority over traffic within the circle. The modern roundabout era began in 1996 with the adoption by Britain of “yield-at-entry” rule for vehicles entering a roundabout, giving vehicles in the circular travelway the right-of-way for the first time. Roundabouts evolved into relatively smaller diameters than traditional circles and now possess splitter islands that constrain speeds at entry. The “yield at entry” modification resulted in increased roundabout capacity and a sharp decline in crashes. The modern roundabout era began.

Roundabouts then spread from Britain to the European continent and British influenced countries, particularly New Zealand and Australia. The first two roundabouts were built in North America in 1990. The 19th in the US and first roundabout in the northeast was constructed at Montpelier, Vermont in 1995. There were about 100 roundabouts in the US and Canada in 1999, and 300 at the end of 2000. Observers expect US and Canadian annual development of roundabouts will reach 1,000 annually within a few years, a construction rate maintained by France for over a decade.

The Air Quality Challenges

Air Quality–Pollutant Emissions and Global Warming

Environmental air quality concerns range from neighborhood to global in scale. Global warming and the ozone layer thinning comprise two universal air-based threats to the earth’s living environment. Fossil fuel pollutant emissions cause immediate and long term direct damage to human health as well as to the balance of ecology.

Polluted air and global warming continue to be major issues for the United States and Canada. US law and a regulatory framework for reducing air pollution, particularly for those below standard (“non-attainment”) areas, date from the US Clean Air Act of 1970. The primary target for reduction to combat global warming, carbon dioxide (CO₂), is not an emission of concern in clean air policy and regulation. Global warming as a substantive concern emerged from

the United Nations Conference on the Environment and Development's "Earth Summit," held at Rio de Janeiro in 1991. Over 150 nations signed the UN Framework Convention on Climate Change, committing them to voluntary actions to stabilize GHGs. As developed nations, the US and Canada committed to reducing GHGs at the Third Conference of Parties to the United Nations Framework Convention on Climate Change at Kyoto in 1997. For the US and Canada this means cutting GHGs "business as usual" projections by 25-30% in the period 2008-2012. The targets for the US and Canada are 7% and 6% respectively below the 1990 levels (US Office of the President, p 21).

Air Pollution and Transportation in the United States

The transportation sector is a major source of GHGs and air pollution emissions. The US transportation sector consumes about 65% of total oil consumption, produces almost a third of US carbon emissions and substantial amounts of most air pollutants (Interlaboratory Working Group, 2000, p 6.1). "Air pollution" as used here refers to the primary pollutants that contribute to damage to health and the larger environment:

1. Smog, a combination of pollutants with direct and indirect health effects and other environmental damage, including a resultant formation of damaging ozone. Transportation emissions contribute a major portion of smog, including substantial amounts of volatile organic compounds (VOCs) and nitrogen oxides (NO_x).
2. Sulfur oxides (SO_x) which cause direct human health damage and constitute the key pollutants that cause acid rain damaging lakes, streams and forests up to hundreds of miles away. Transportation contributes a significant amount to this factor.
3. CO directly causes negative health affects and contributes to smog. Transportation produces two-thirds of CO emissions in the US, mostly from motor vehicles (Fueling Vermont's Future, I, p 3-8).
4. CO₂ that in itself comprises the major global warming gas as noted above. Each gallon of motor fuel generates 19.6 pounds of CO₂.
5. Particulates, microscopic particles, commonly called soot, can be absorbed over time in the lungs and cause respiratory disease and exacerbate other circulatory or respiratory ailments. Larger trucks and buses alone contribute to over half the soot from motor vehicles

(Rolling Smokestacks, p 2). Overall transportation contributes to less than 10% of particulate pollution.

Some progress has been made since 1970 in the US in reducing several pollutants, particularly in erasing atmospheric lead through eliminating lead in motor fuels. However, increased vehicle miles of travel continue to add NO₂ and CO₂ emissions. And, “US transportation energy consumption and greenhouse emissions are expected to grow robustly over the next few decades (US Department of Energy, 2000, Chapter 6.1).” Within this context, CO₂, CO, VOCs and NO_x are the compounds that, when empirically measured, determine whether an air shed meets (attainment) or fails (non-attainment) United States air quality standards. Particulates and CO are subject to separate standards for attainment and non-attainment. US Federal air pollution standards for the transportation sector over the past two decades have improved air quality or dramatically slowed its decline. A rapid increase in the GHG CO₂, is a clear exception.

Intersection Modeling for Energy Consumption and Emissions

The modern roundabout is acknowledged to be generally superior to other forms of intersection control in the areas of capacity, user delay, and safety. Most early roundabout research and assessment focused on capacity, delay, and effective design. Australia first developed fuel consumption models in the late 1970s and over time expanded them to include major pollutants. Only in the 1990s did the question of intersection control and emissions begin to receive the attention of North American researchers. The US Environmental Protection Administration (EPA) Mobile 5 model (Mobile) does not contain a module that effectively models intersection performance. The Mobile computer program first developed in 1978, was built on sets of equations, assumptions, and adjustments to laboratory and field tests. Factors for translating fuel consumption to specific emissions are provided for each area of the country. States must use Mobile in determining air quality planning, effectiveness of different strategies, and measuring results. “Mobile” measures three pollutant emissions: CO, NO_x, and HC (US General Accounting Office, 1997, p 1). One Federal Highway Administration (FHWA) policy administrator

viewed Mobile as only providing gross estimates of transportation emissions (Savonis, 2000, p 2).

Australia Develops Models with Environmental Applications

As a result of policies emphasizing cost efficiency in selecting highway investments, Australia developed intersection fuel consumption models and software about the time the roundabout began to be used significantly there. The roundabout was added to the analytical software, SIDRA¹, and this software in the North American version operates in conformance to the highway practice manual, the US “Highway Capacity Manual.” SIDRA which, in a single software, models and compares performance of all intersection control options, is the most user friendly, versatile, and comprehensive tool for transportation planners and engineering practitioners. British software is considered the most refined design software for roundabouts.

Australian concern for cost efficiency in highway investments required an analytical procedure, a micro model, to determine the relative performance of signals, stop control, and eventually roundabouts. The software, SIDRA-2, released in 1982 (Bowyer, Akcelik and Biggs, 1985, p 24) was one of the first to model vehicle fuel consumption based on a four-part cycle: cruise, deceleration, idle and acceleration to cruise.

Figure 1 provides a clear outline of fuel consumption during four phases a vehicle encounters at an intersection: cruise, deceleration, stop, and acceleration to cruise—all are scaled by time, distance, and speed (Bowyer, Akcelik and Biggs, 1985, p 3). Clearly vehicles stopping and accelerating utilize far more fuel than during cruising, and fuel used while idling in stop delay at intersections uses far less fuel than either acceleration or cruise phases.

¹ SIDRA is a generic description of a software product that has gone through several editions. Originally produced under the Australian Road Research Board, its development and distribution transferred in 1999 to Akcelik and Associates, Victoria. The current edition is aaSIDRA.

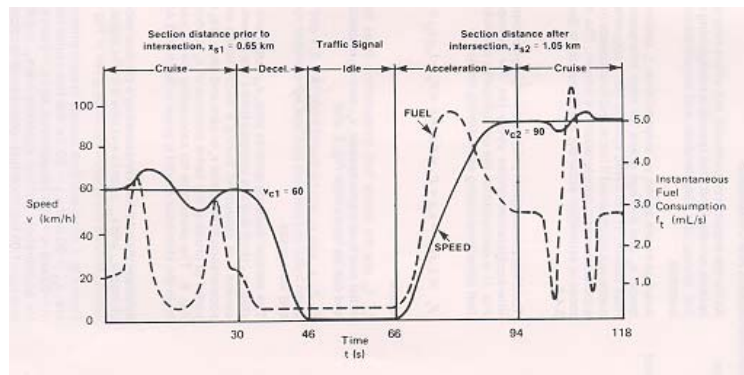


Figure 1: Speed Time Trace and Instantaneous Fuel Consumption (Bowyer, Akcelik and Biggs, 1984)

Starting in 1982 emissions, energy consumption, and cost components began to be added. SIDRA now models intersection performance for the following: pollutant emissions (HC, CO, CO₂, NO_x, and lead); delay (stopped, queuing, geometric, overall); energy (fuel) consumption, and operating cost. In order to predict performance, SIDRA models each travel lane, and both light and heavy vehicles.

Previous studies and other models have addressed intersection environmental performance. Other researchers identified differentials in emissions between roundabouts and traffic signals (Hoglund, 1993; Garder, 1998). A Swedish model, CAPCAL 2, released in 1996 also calculates performance measures, including vehicle costs and emissions, for all intersection types (Hagring, 1997). Other studies are centered on the intersection cycle of emissions at signalized intersections (Colyar, Frey, Rophail and Unal, 2000). The latter study determined that the stop and go cycle produced about twice the amount of emissions when compared to Mobile analysis predictions

Specific Intersection Research, Analyses and Assessment

Thessaloniki, Greece

A research paper (Mustafa and Vougias, 1993) tested SIDRA against known measured emissions at an intersection where a roundabout was replaced with a traffic signal. Measurements at the intersection of CO, HC and NO_x at a monitoring station showed a clear relationship between traffic levels and emission levels. The SIDRA simulation using the intersection traffic data revealed lower emissions for the roundabout for all four pollutants over a wide range of traffic volumes.

East Lansing, Michigan

A roundabout related study compared three stop control intersections and three small traffic circles at Michigan State University at East Lansing, Michigan (Savage and Al-Sahli, 1994). Traffic circles tend to be large—300 to 400 feet and more in diameter—and high speed.

The circles in this study were small, 150 feet in diameter, and similar in size to a moderate size, multi-lane roundabout. All but one approach to one intersection were two-lane divided roads with medians. All intersections experienced considerable bicycle and pedestrian traffic. Daily traffic on 14,633 to 23,710 vehicles. All six intersections were modeled along with changing the three stop control intersections to traffic circles. Using a NETSIM, a US intersection traffic model, the circles out performed the stop control in all categories, including safety, pollutant emissions (HC, CO and NO_x) fuel consumption, and delay. Historic vehicle and bicycle crashes and injuries were substantially less at the circle intersections.

Vermont Keene Turn Roundabout

The first multi-lane roundabout and one at an interstate interchange in the northeastern US, “Keene Turn,” opened in Brattleboro, Vermont, October 1999. The Vermont Agency of Transportation (VAOT) (Vermont Agency of transportation, 2000) carried out stop delay

measurements at the signalized intersection in 1999 and at the roundabout in 2000. Peak hour traffic in both years was approximately 2,800 with total entering vehicles 28,000 daily in 2000. Three approaches were single-lane highways, and the I 91 Exit was two-lane. The signal did provide a dedicated left hand turning phase on all approaches.



Keene Turn Roundabout, Brattleboro, Vermont

Table 1 summarizes a.m. and peak hour data recorded. Note that during the lower a.m. traffic period, signal delay remained practically unchanged compared to the over 50% drop in delay for the roundabout. Taking an arbitrary overall delay figure midway between the a.m. and p.m. delay—26.5 seconds delay for the 28,000 average daily traffic translates to a reduction of 75,231 hours yearly of stop delay. This does not account for geometric delay or delay represented by deceleration and acceleration from cruising speed, which, together, would also tend to increase the advantage of the roundabout over a signal.

To translate stop delay to fuel usage, the parameter from the US SIDRA version (SIDRA Input Guide, 1988, p 123) of 0.41 gallon per hour applied to the 75,231 hours of stop delay translates to an annual motor fuel consumption decrease of 30,845 gallons.

Table 1
SIGNAL DELAY 1999 AND KEENE TURN ROUNDABOUT
DELAY 2000 AT INTERSECTION OF US 5, I 91, AND VT 9

<u>Peak Hour</u>	<u>1999 Traffic Signal</u>		<u>2000 Roundabout</u>		<u>Change</u>
	<u>Delay (sec)</u>	<u>Vehicles</u>	<u>Delay (sec)</u>	<u>Vehicles</u>	<u>(sec)</u>
A.M.	44	1,216	12	1,870	-33
P.M.	46	2,764	26	2,812	-20

NOTES: 1. Video was used to measure 1999 delay. At times queues were beyond video range and therefore traffic signal delays are understated.
2. On-site methods were utilized to measure roundabout stop delay.

Maine

Maine's first roundabout replaced a stop-controlled intersection. An assessment that included field measurements of this four-leg intersection with about 13,000 daily entering vehicles, concludes there is a reduction in delay of about 5,000 to 10,000 hours annually and a reduction of emissions compared to a signal alternative (Garder, 1998, pp 7 and 43). Garder stated traffic "slowing to 15 mph and keeping that speed through a junction and then accelerating back up to a 'normal' travel speed will cause less pollution than a vehicle that is repeatedly forced into stop-and-go condition (Garder 1998, p 45)." The estimated stops per day were 3,500 with the roundabout in place compared to the 12,000 with the prior stop control.

Clearwater, Florida: Federal Transportation Air Quality Programs and Roundabouts

In 1999 the City of Clearwater, Florida, submitted one of the first proposals for FHWA funds under the Congestion Management and Air Quality (CMAQ) program administered by the State of Florida (City of Clearwater, 1999). CMAQ funds must be used in states with non-attainment air sheds for projects that improve air quality. The Clearwater “Gateway Roundabout” application (City of Clearwater, 2000) proposed a single, two-lane roundabout to replace three signalized intersections and one stop controlled intersection. EPA’s Mobile (Mobile5) limitations only allowed roundabout benefits over signals for stop delay when comparing Gateway Roundabout to other CMAQ competing proposals. The emissions reduction based on stop delay were 68%, less for the roundabout compared to the signals. Using the SIDRA default figure of 0.41 gallons of motor fuel per hour of “stop delay” (idling), the annual motor fuel reduction totals for the 125,779 hours of delay was 51,569 gallons.

Since idling uses less fuel than the acceleration and deceleration phases—a factor SIDRA does model—the SIDRA results were also reported by Clearwater. SIDRA assessment predicted emissions for the stop delay period at about a fifth of the overall fuel and emission reductions that would be attained with the new roundabout. Annualized fuel savings and emissions reductions predicted by SIDRA were (City of Clearwater, p 6):

579,255	gallons of motor fuel
17.4	tons of HC
438.5	tons of CO
19.3	tons of NO _x
12,409	tons of CO ₂

The Gateway Roundabout--without CMAQ funding--was built in late 1999 and significantly improved traffic operations from previous conditions.

Fort Collins, Colorado and CMAQ

Fort Collins, Colorado received a CMAQ grant and construction is scheduled for summer 2001 of a multi-lane roundabout serving as the junction of a four-lane and six-lane highway. Initially the roundabout

is to be two-lane. The single roundabout option provides the same fuel consumption and air quality benefits at grade and at half the cost compared to a grade separated facility that also employs a single roundabout for interchange. The roundabout at grade cost estimates range from \$2.8-\$3.1 million and the roundabout grade separated \$5.4-\$5.7 million (Moe, Bracke and Crown, p 26). Both options attain the same level of air quality and stop delay. In terms of air quality and delay, the emissions and delay of the no-build were so extreme on the four-lane highway as to be un-measurable. The roundabout options each resulted in a reduction of 225 hours of delay daily and 11 kilograms of CO daily compared to only the six-lane road generation of 880 hours delay and CO of 44 kilograms (Moe, Bracke and Crown, p. 27).

Montpelier US 2/US 302 Intersection

A three-leg Montpelier, Vermont, intersection study (City of Montpelier, 2000) provides a clear example of SIDRA fuel consumption in an intersection with projected traffic near the limit of the capacity of a one-lane roundabout. This study reflects a peak hour fuel saving of 92.9 gallons daily compared to a signal alternative. This can be extrapolated by a factor of ten to determine daily differential of 929 gallons, and annualized consumption reduction of 339,085 gallons reduction compared to the signal alternative. Substantial reductions were also predicted for other air pollutant emissions and CO₂.

Area and State Fuel Consumption and GHGs Potential Decrease from Roundabout Installations

The potential impact of transforming busy signalized intersections to roundabouts can be easily calculated from applying the Montpelier annual fuel savings, 330,000 gallons, to a larger set of intersections. Using this number from a one-lane intersection appears to be a fairly conservative yardstick to apply to likely group of single and multi-lane installations. For example, applying modeled reductions of the magnitude of the Montpelier US 2/302 intersection to a retrofit of 100 busy signalized intersections to roundabouts control statewide in Vermont results in a reduction of approximately 33 million gallons

annually. A motor fuel reduction of this magnitude is the equivalent of approximately 8% of the 1997 total Vermont motor fuel consumption of 401 million gallons (FHWA, 1998, p I-3). Air pollution emissions and particularly GHGs in the form of CO₂ are tied directly to fuel consumption.

Roundabouts also provide short term and long term savings that may approach or exceed immediate reductions at a specific intersection:

1. Short term-- higher performance of existing circulation in builtup areas as well as sharply improved conditions for walking and bicycling (Redington, 1999).
2. Long term--increased development densities as the result of increased access and service--for all modes but particularly for those walking and bicycling (Redington, 1999).

The emissions, GHGs, and fuel consumption benefits of these other short and long term benefits are not included in the potential benefits evaluated here in this paper. Certainly, these additional benefits need to be researched to determine their magnitude.

Global Warming--Possible Contribution of Roundabouts

Global warming strategic and implementation plans have been developed in both the US and Canada in response to the establishment of the Kyoto GHGs reduction goals for developed nations. The Canadian national plan for transportation (Transportation Climate Change Table, 1999) was generated through a collaborative effort of the Canadian and provincial transport ministries.

The City of Burlington through local initiative completed a planning process with a goal for GHGs reductions reflecting the Kyoto target. The difficulties of formulating plans and starting implementation at the national level are manifold for both the US and Canada (Butt, 2000). State, provincial and metropolitan plans in North America do not yet include roundabouts along with associated pedestrian facilities as a strategic element in transportation plans--the current Toronto strategic plan is an example (Greater Toronto Services Board, 2000). The roundabout does present another substantial element of

automobile “attrition” as the term is used by Toronto urbanologist, Jane Jacobs (Jacobs, 1961, pp. 348-349, p. 359).

Burlington “set a target for 2005 of reducing GHGs emissions in Burlington 10 percent below 1990 levels (City of Burlington, 2000, p 5). The first steps in creating the structure and initiating implementation and monitoring are now underway. The 1990 Burlington population of 37,712 (largest in Vermont) is the largest component of the Burlington metropolitan statistical area about 150,000. The area population is growing at a moderate pace, about 10-15% per decade.

At the metropolitan level, the roundabout savings at busy intersections represents a tool to meet the Burlington goal of reducing 2005 GHGs generation by 256,000 tons. Transforming 25 signalized intersections with substantial traffic volumes would, based on the Montpelier case modeled by SIDRA, amount to about 61,000 tons of CO₂. This estimates is based on assuming 250,000 annual reduction in fuel use per intersection average and 19.57 pounds of CO₂ per gallon of motor fuel. The immediate GHG reduction from the replacement of 25 traffic signals at busy intersections to roundabouts would represent about 24% GHGs reduction necessary for Burlington to return to 10% below the 1990 generation levels by 2005.

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